



POWER AND MOBILITY



EVALUATING VOLTAGE REGULATION COMPLIANCE OF MIL-PRF-GCS600A(ARMY) FOR VEHICLE ON-BOARD GENERATORS AND ASSESSING OVERALL VEHICLE BUS COMPLIANCE

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Presentation Overview

- Objectives
- Background
- Experimental Setup
- Characterization and Power Quality Test Procedures
- Experimental Results
- Modeling
- Simulation Results
- Modeling Parameter Variation
- Conclusions
- Future work

Objectives

- Component level compliance with MIL-PRF-GCS600A(ARMY)
- Identification of parameters on power generation components
- Electrical machine characterization
- Modeling
- System level power quality compliance
- Optimization of high-voltage bus capacitance

Background

Background MIL-PRF-GCS600A(ARMY)

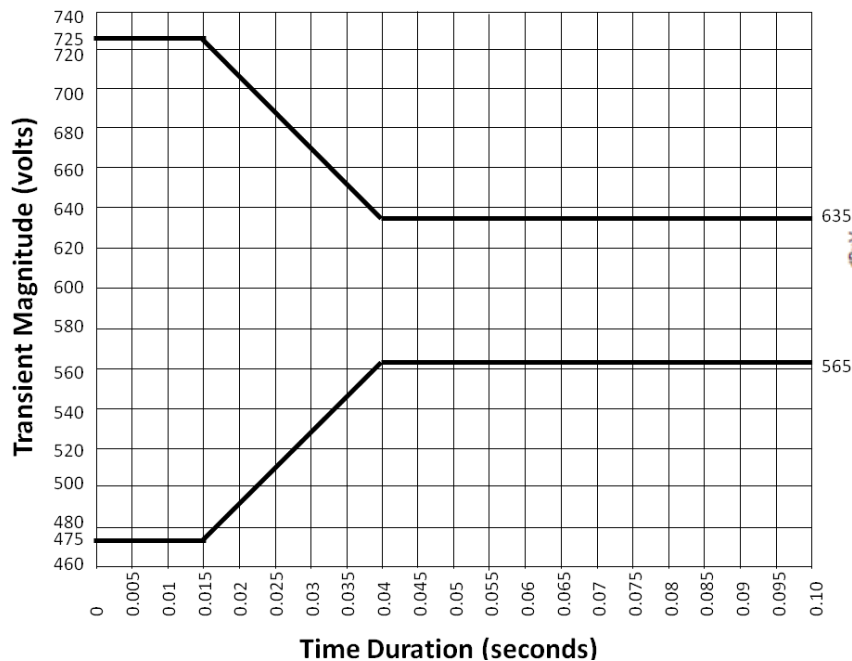
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3.1.3 Electrical Characteristics

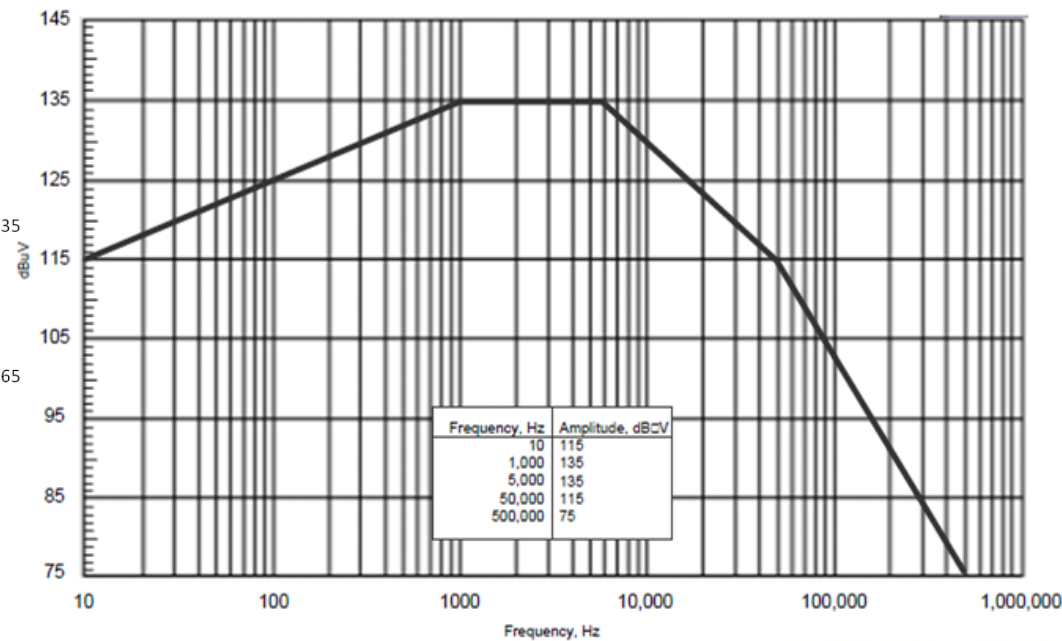
Steady-state Voltage	565V – 635V (600V ± 35V)
Ripple Amplitude	9V
Distortion Factor	0.015

$$\text{Distortion Factor} = \frac{\sqrt{\sum_{h=1}^{\infty} V_h^2}}{V_{DC}}$$

- Normal Transients: 475V – 725V for 15ms



- Distortion Spectrum

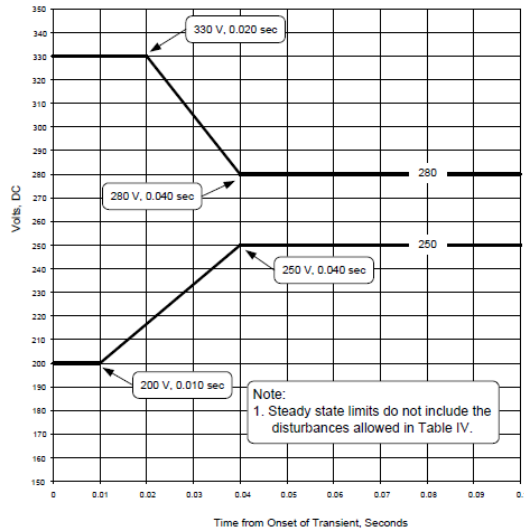


Background

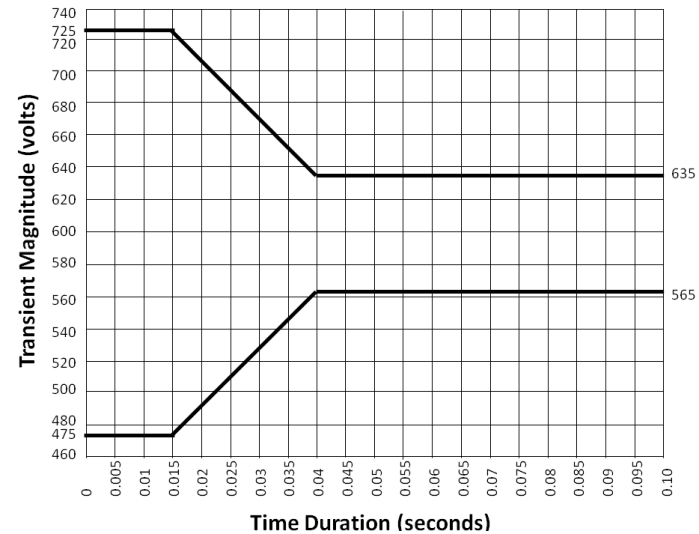
MIL-STD-704F vs. MIL-PRF-GCS600A(ARMY)

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- Normal Transients



- MIL-STD-704F (270VDC)



- MIL-PRF-GCS600A(ARMY) (600VDC)

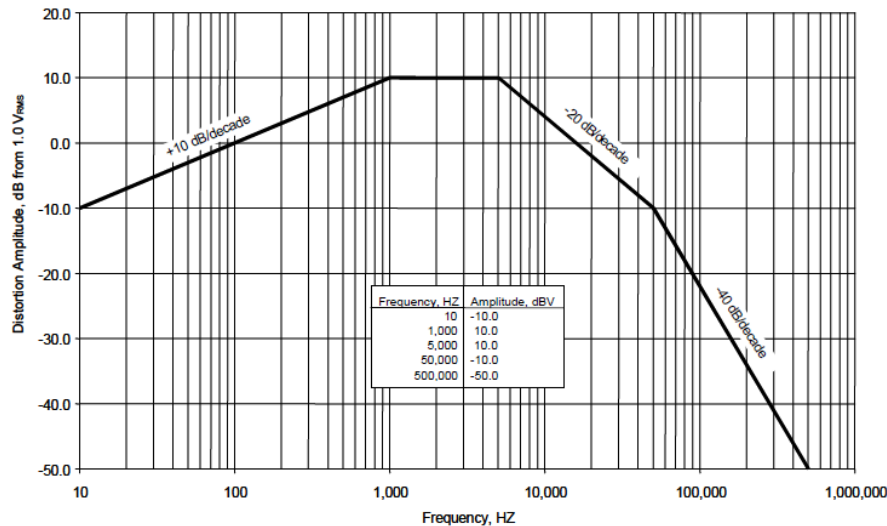
Specification	MIL-STD-704F (270VDC)	% of Nominal	MIL-PRF-GCS600A(ARMY) (600VDC)	% of Nominal
Steady-State Voltage	250V - 280V (270V +10V / -20V)	11.1%	565V - 635V (600V ± 35V)	11.7%
Normal Transients	200V - 330V for 20ms (up) / 10ms (down), 40ms settling time	48.1%	475V - 725V for 15ms, 40ms settling time	41.7%
Ripple Amplitude	6V	2.2%	9V	1.5%

Background

MIL-STD-704F vs. MIL-PRF-GCS600A(ARMY)

POWER AND MOBILITY

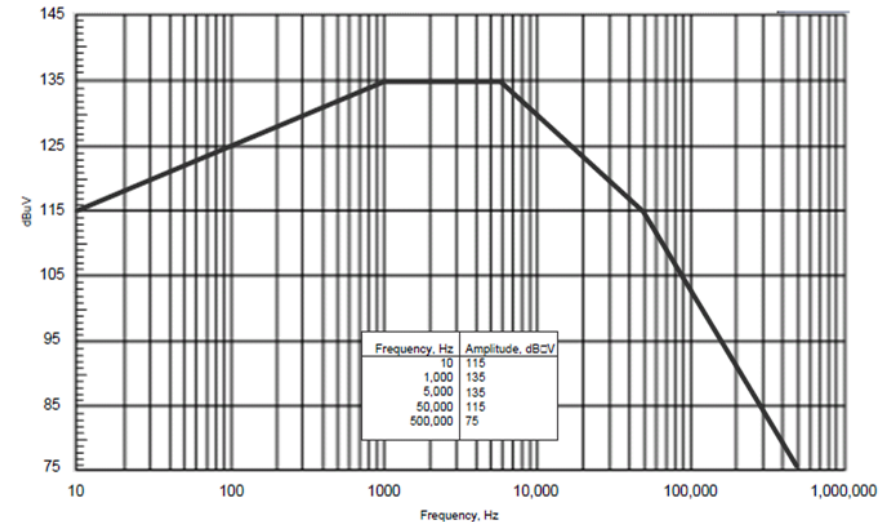
Distortion Spectrum



• MIL-STD-704F (270VDC)

- Distortion Factor: 0.015

Frequency	Amplitude, dBV	Amplitude, V	% of Nominal
10	-10	0.316	0.12%
1000	10	3.16	1.2%
5000	10	3.16	1.2%
50,000	-10	0.316	0.12%
500,000	-50	0.00316	0.0012%



• MIL-PRF-GCS600A(ARMY) (600VDC)

- Distortion Factor: 0.015

Frequency	Amplitude, dBμV	Amplitude, V	% of Nominal
10	115	0.562	0.09%
1000	135	5.62	0.9%
5000	135	5.62	0.9%
50,000	115	0.562	0.09%
500,000	75	0.00562	0.0009%

Background: Typical Vehicle Architecture

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• Vehicle Loads

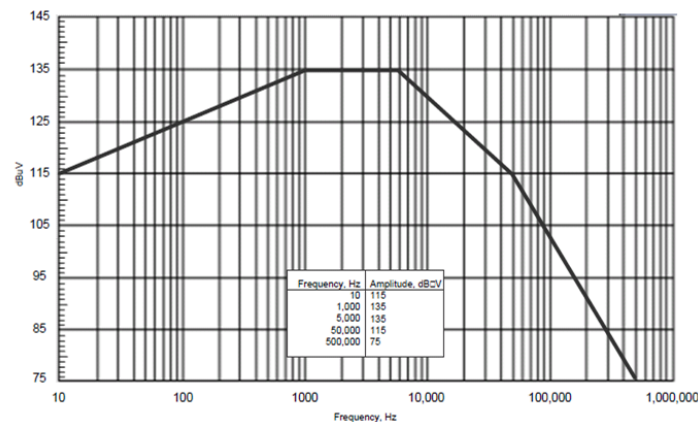
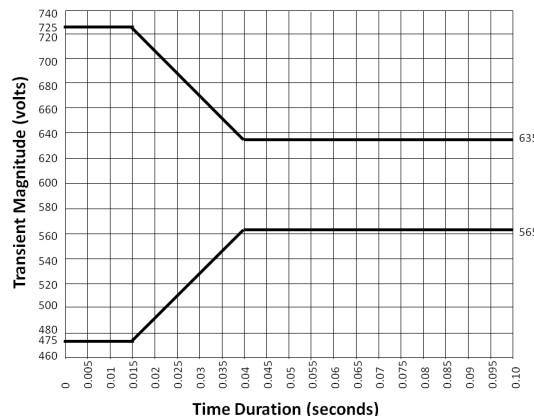
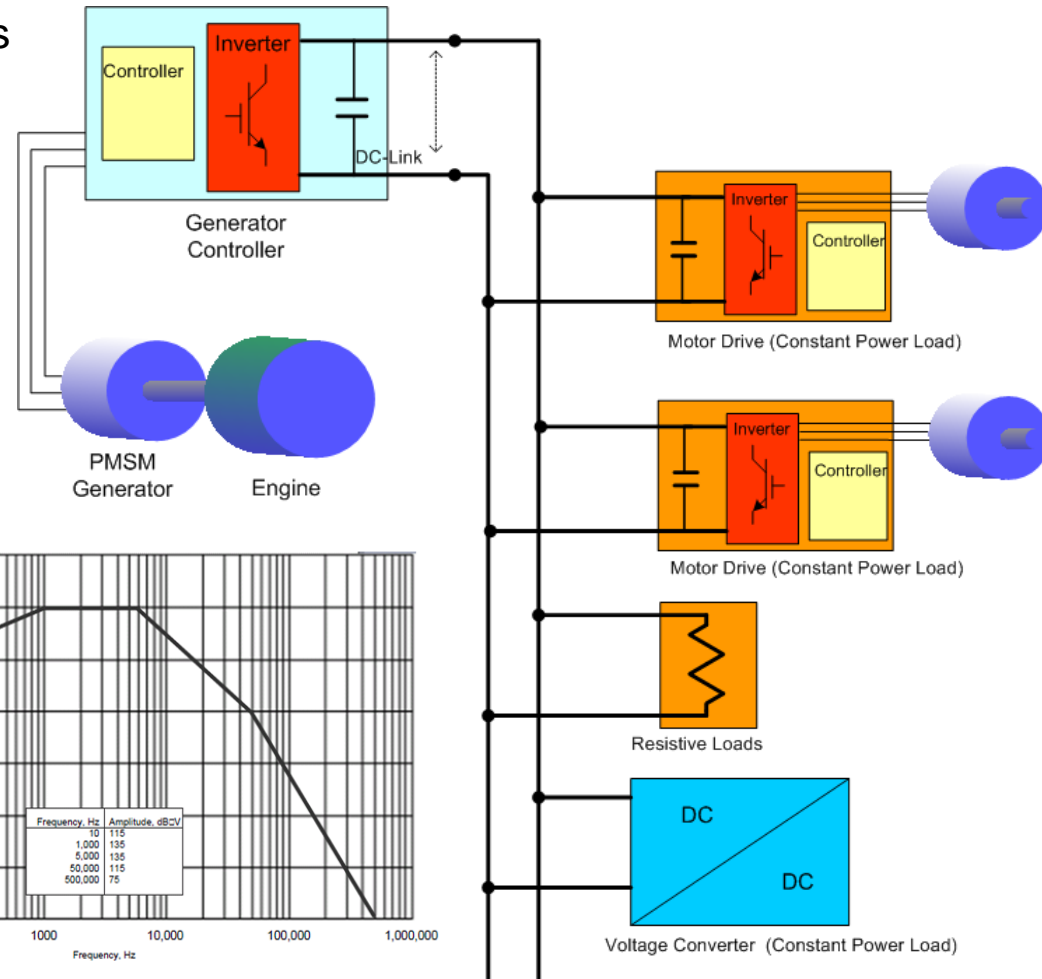
— Motor Drives & Voltage Converters

- Constant Power
- Capacitive (dc-link)
- Switching noise

— Resistive Loads

— Inductive Loads

- EMI filters
- Phase Margin Reduction



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-

- Vector Control

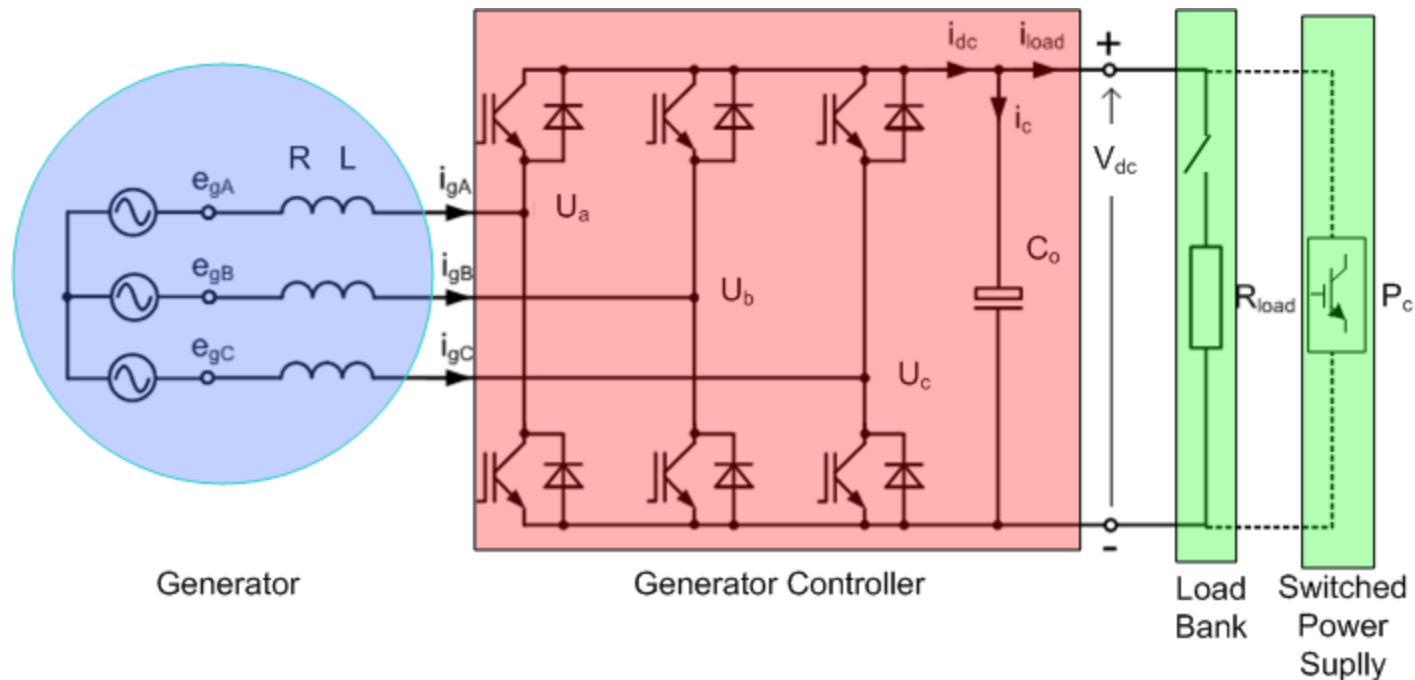


Experimental Setup

Electrical Diagram of Setup

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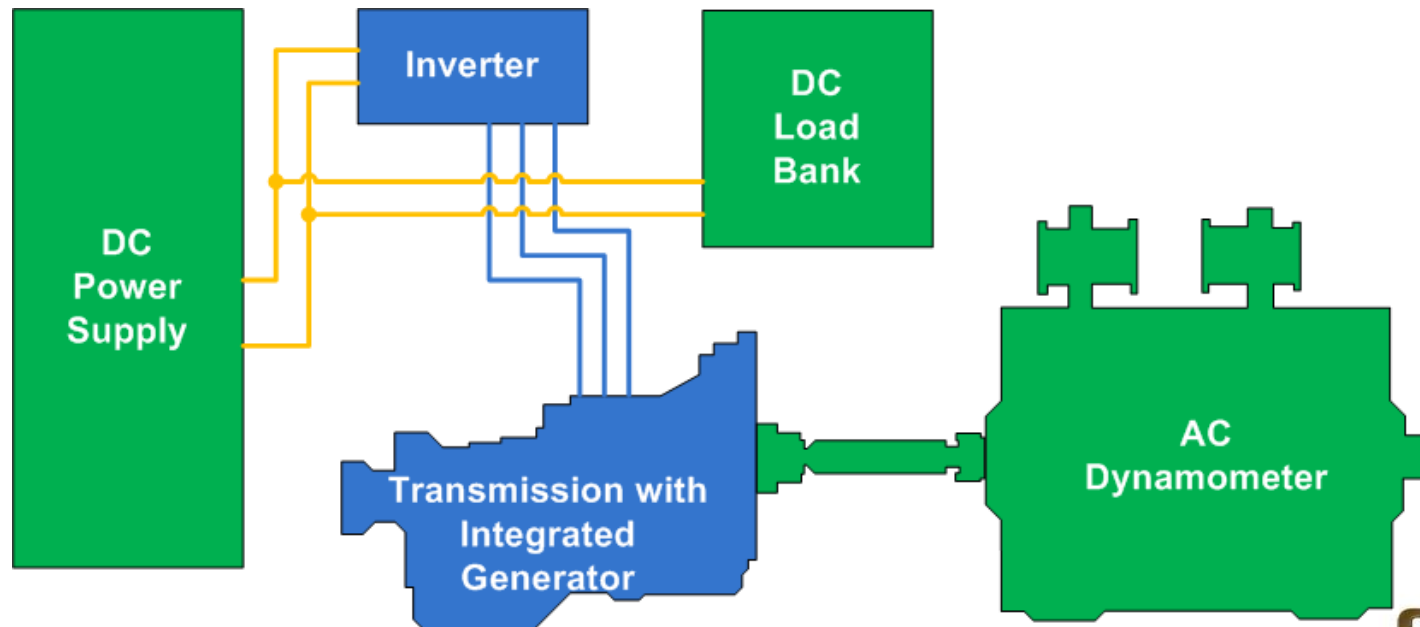
- Generator, Inverter and Load Equivalent Circuit



Experimental Setup

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- AC Dynamometer
 - Constant Torque: 1244N·m from 0-2,000rpm
 - Constant Power: 260kW from 2,000-10,000rpm
- DC Power Supply
 - 900V / 1000A / 250kW
- DC Load Bank
 - 250kW in 5kW Steps
- Temperature and Flow Regulated PGW cooling loops



Characterization and Power Quality Test Procedures

TARDEC's Standardized Tests and Evaluations

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● Traction Motor ● Servo Motor ● Generator ● Alternator ● DC/DC Converter

Machine Characterization

● ● ● ●

- Winding Resistance Characterization
- Inductance Characterization
- Back EMF Measurement and Characterization
- Rotor Inertia
- Spinning Losses (Iron Loss, Friction, Windage) – Spin Down Test

Drive Performance Validation/Determination

- Maximum Electrical Speed ● ● ● ●
- Maximum Starting (Stall) Torque ● ●
- Torque Ripple ● ● ●
- Speed / Torque (Current) Envelope Continuous ● ●
- Efficiency ● ● ● ● ●
- Speed vs. Power Envelope (Continuous) ● ●

Drive System Controllability

- Speed Regulation / Response ● ●
- Torque (Current) Response ● ● ● ●
- Voltage Regulation / Response ● ● ● ●

System Robustness

● ● ● ● ●

- Fault Tolerance
- Reliability Evaluation
- Conducted EMI Evaluation

Drive System Integration Practicability

● ● ● ● ●

- Safety Evaluation / Testing
- SWaP-C Evaluation
- Power Quality Compliance (MIL-PRF-GCS600A(ARMY) / MIL-STD 704/1275)
- Current Harmonics

Drive System Technology Readiness Level (TRL)

Power Quality Testing Scenarios

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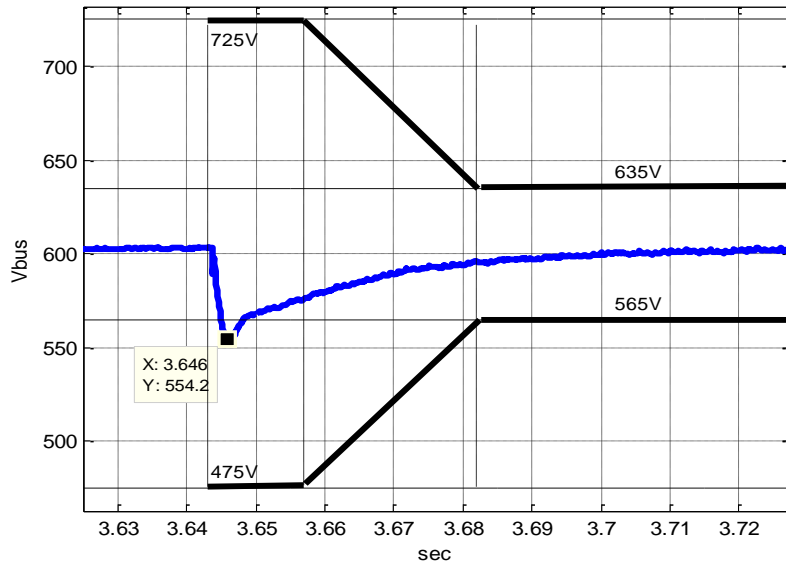
- 4.2.1 Voltage Regulation to Step Load.
 - *All power sources shall be bench tested with a simulated load profile (equivalent to the worst case operation of the system) to verify that electrical characteristics meet normal transient performance.*
 - 19 → 88kW resistive load bank step, 1800rpm
 - 88 → 19kW resistive load bank step, 1800rpm
 - 0 → 50kW resistive load bank step + 19kW constant power (2700μF), 1800rpm
- 3.1.1.11 Distortion Spectrum.
 - *The distortion spectrum is defined as the maximum allowable limit of distortion expressed in decibels above 1 microvolt as a function of frequency.*
- 3.1.1.12 Distortion Factor.
 - *The distortion factor is defined as the ratio of distortion to the steady state voltage.*
 - 19kW resistive load bank, 1800rpm
 - 88kW resistive load bank, 1800rpm
 - 50kW resistive load bank + 19kW constant power (2700μF), 1800rpm

Experimental Results

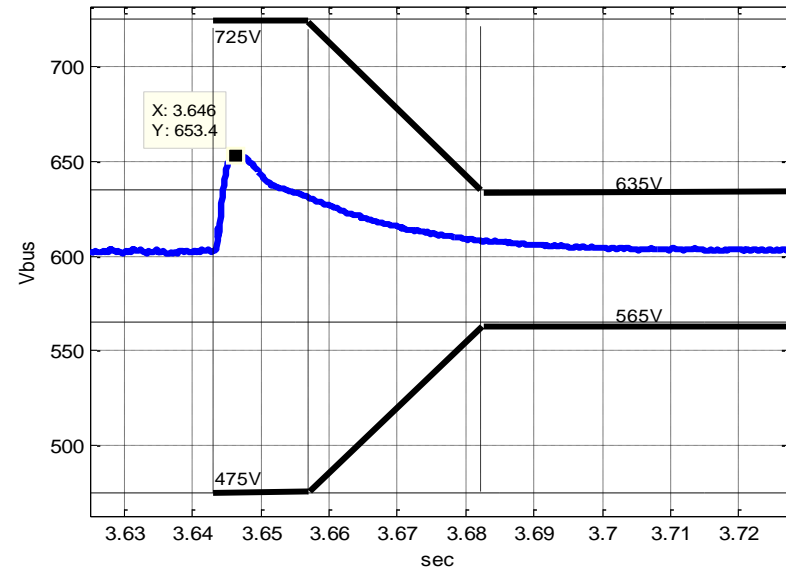
Experimental Results – Voltage Transient Response

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4.2.1 Voltage Regulation to Step Load



19 → 87kW resistive load bank step, 1800rpm

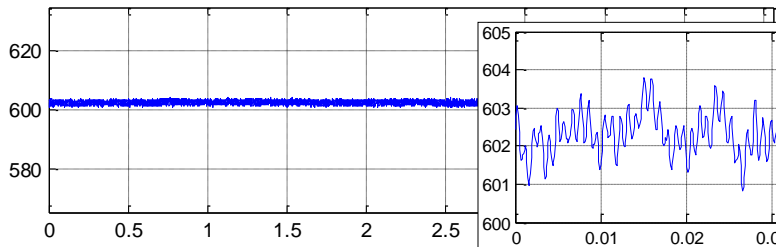


87 → 19kW resistive load bank step, 1800rpm

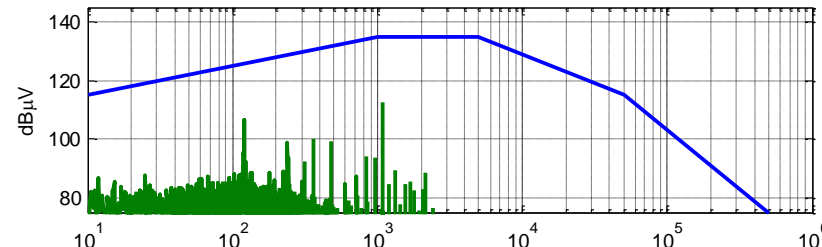
Experimental Results - Steady State

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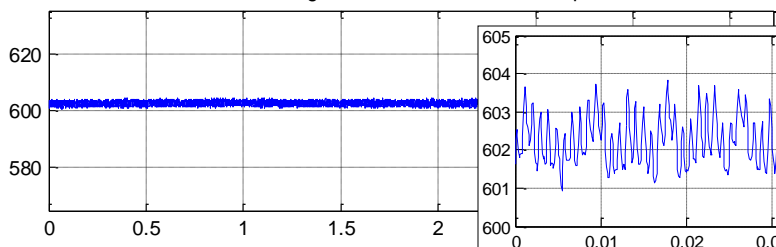
Bus Voltage, 18.7kW Load Bank, 1800rpm



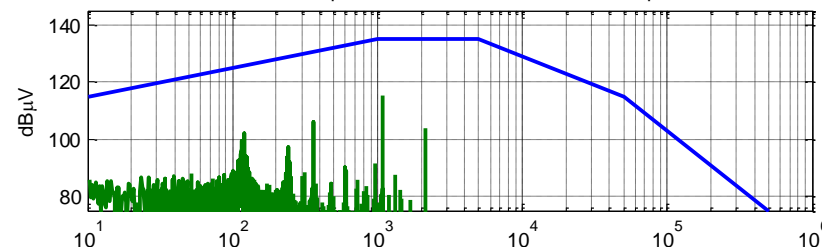
Distortion Spectrum, 18.7kW Load Bank, 1800rpm



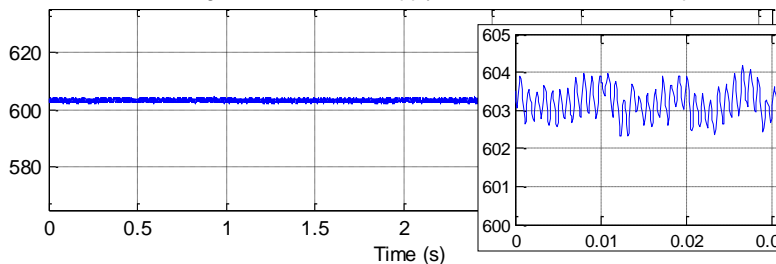
Bus Voltage, 87.8kW Load Bank, 1800rpm



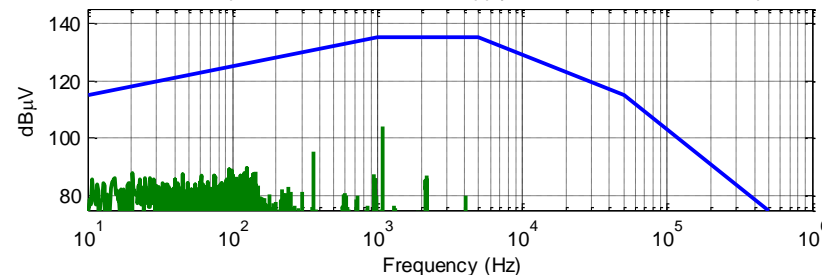
Distortion Spectrum, 87.8kW Load Bank, 1800rpm



Bus Voltage, 18.7kW Power Supply, 50.1kW Load Bank, 1800rpm



Distortion Spectrum, 18.7kW Power Supply, 50.1kW Load Bank, 1800rpm



Distortion
Factor

0.0012

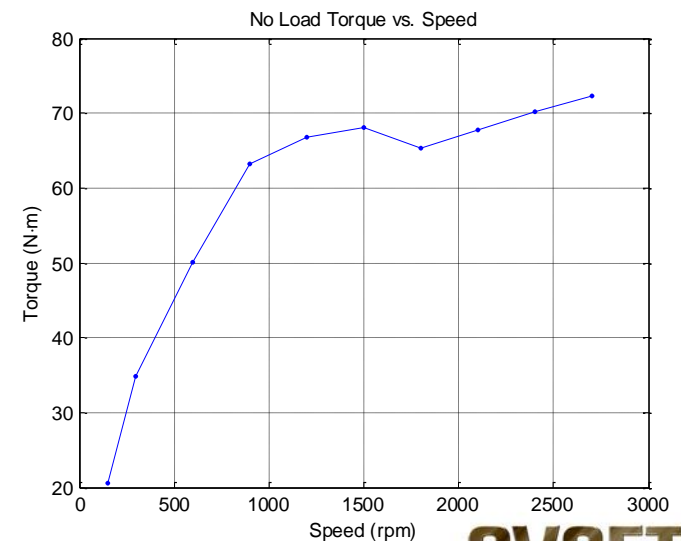
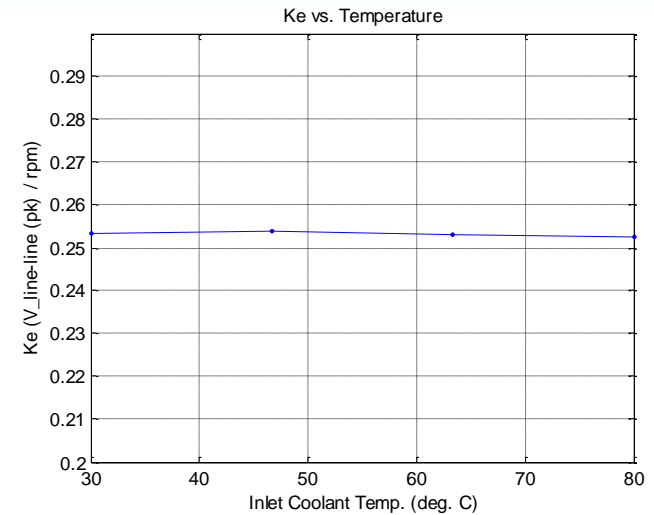
0.0015

0.0010

Machine Characterization

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- Voltage Constant $K_e = 0.253 \text{ V}_{ll(pk)} / \text{rpm}$
 - Negligible variation across speed (150rpm - 2700rpm) and temperature (30C, 46.7C, 63.3C, 80C)
- Phase resistance $R_s = 10.7 \text{ m}\Omega$
- Friction (combined Coulomb (static) and viscous (dynamic))

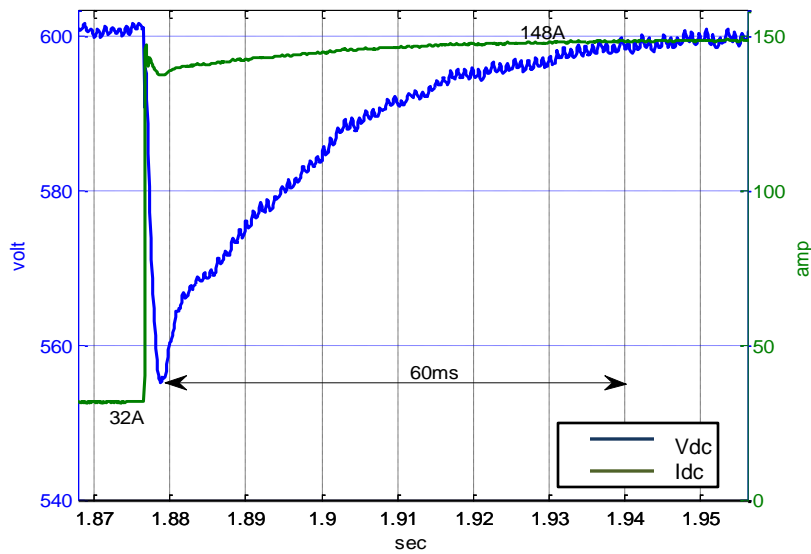


Electrical and Mechanical Response Estimation

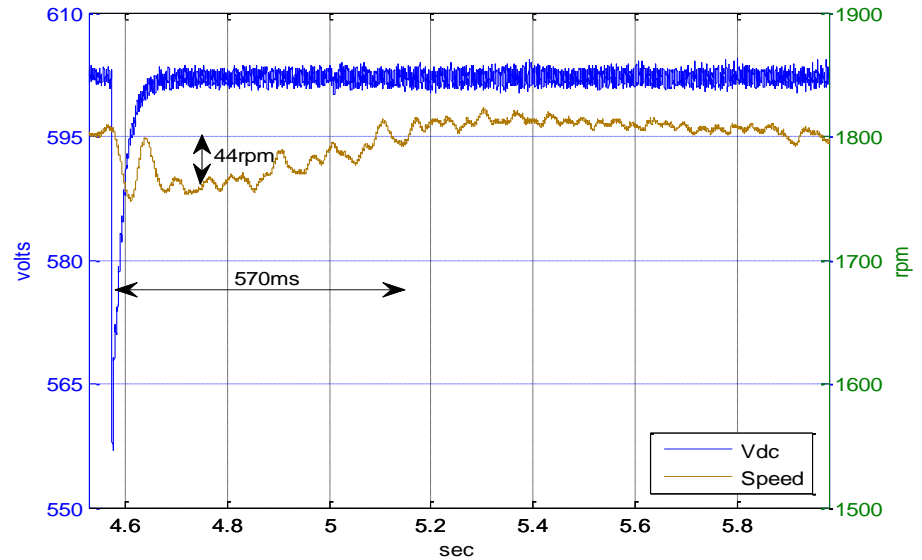
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19 → 87kW resistive load bank step, 1800rpm



Voltage Transient: ΔV 48V and 60 msec



Speed Transient: Δ 44rpm and 570 msec

Modeling

Modeling Effort

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Objectives:

- 1) Evaluate the required amount of bus capacitance need for bus stability
- 2) Assess the total vehicle electrical system's compliance to MIL-PRF-GCS600A(ARMY)

Procedure:

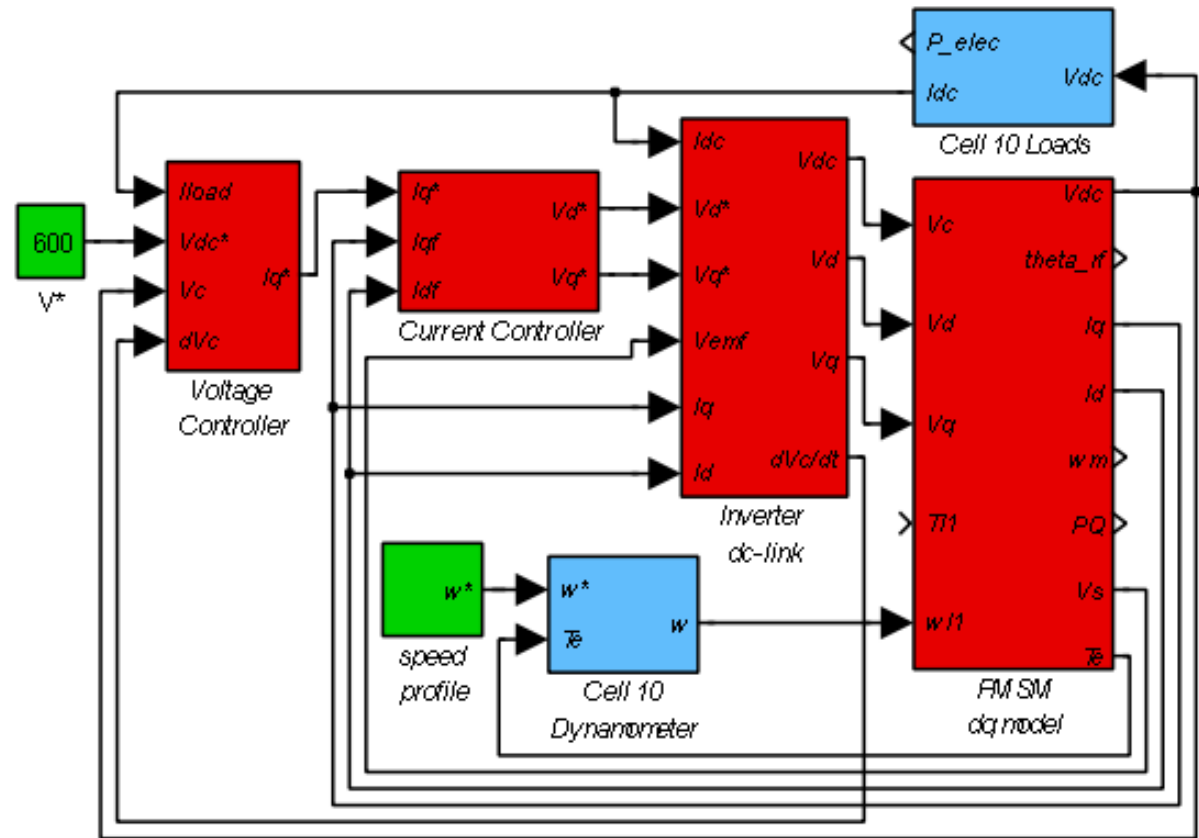
- 1) From test data develop a model of the generator/controller system
- 2) Compare simulation results with experimental results to validate the model
- 3) Adjust generator/controller model's dc-link and apply load transients
- 4) Incorporate the generator/controller model into a vehicle electrical system model

Modeling: Experimental Setup

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Models:

- Generator Controller
 - Voltage
 - Current
- Power Stage
 - Inverter
 - Dc-link
- Generator
 - dq frame of reference
 - Speed input
- Loads
 - Switchable Resistance
 - Constant Power
- Dynamometer
 - Speed Command
 - Torque response



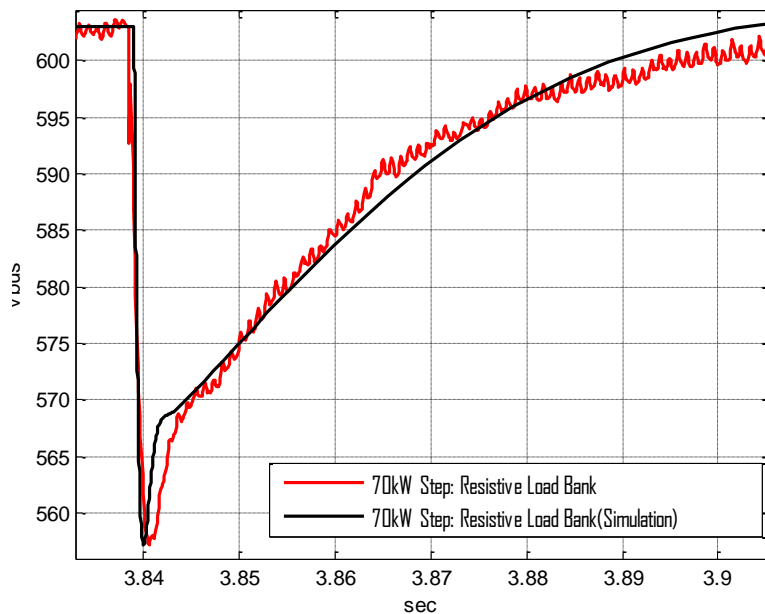
Simulation Results and Modeling Parameter Variation

Modeling: Experimental Validation

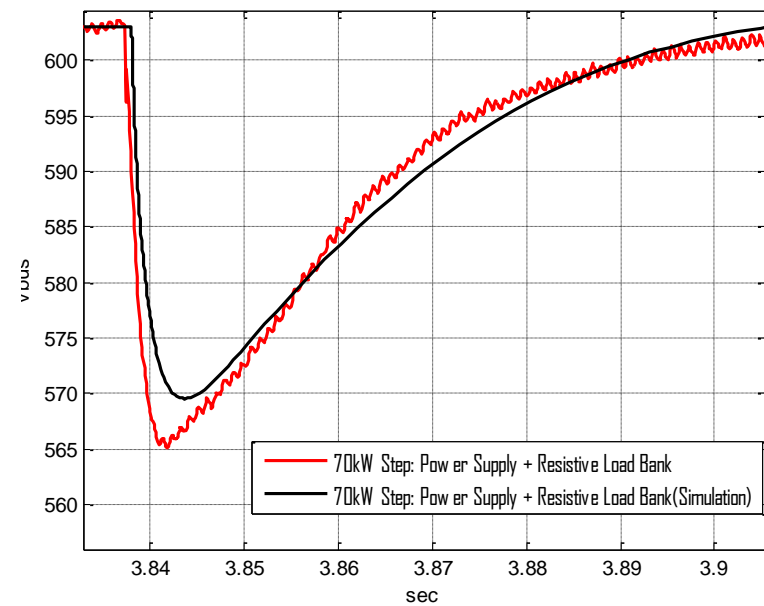
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Comparison between Experimental and Simulation Results: Voltage Transient

70kW Resistive Step Load



70kW Resistive Step Load +Constant
Power Load (Lab Power Supply)

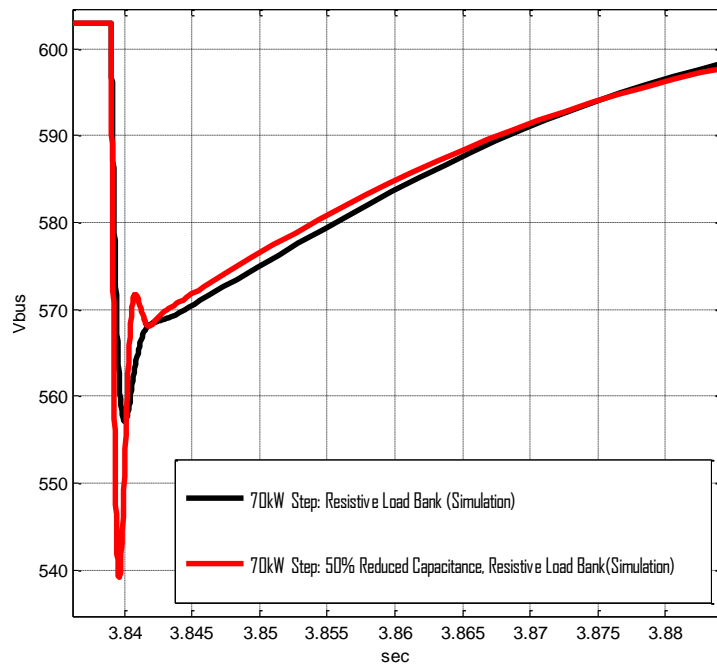


Modeling: Evaluation of Generator/Controller Capacitance

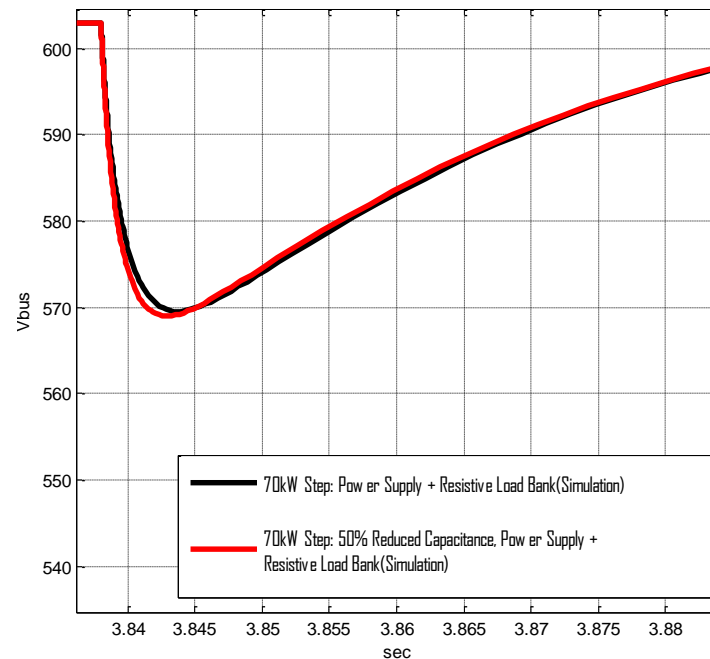
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Comparison between 100% and 50% dc-link capacitance: Voltage Transient

70kW Resistive Step Load



70kW Resistive Step Load +Constant Power Load (Lab Power Supply)

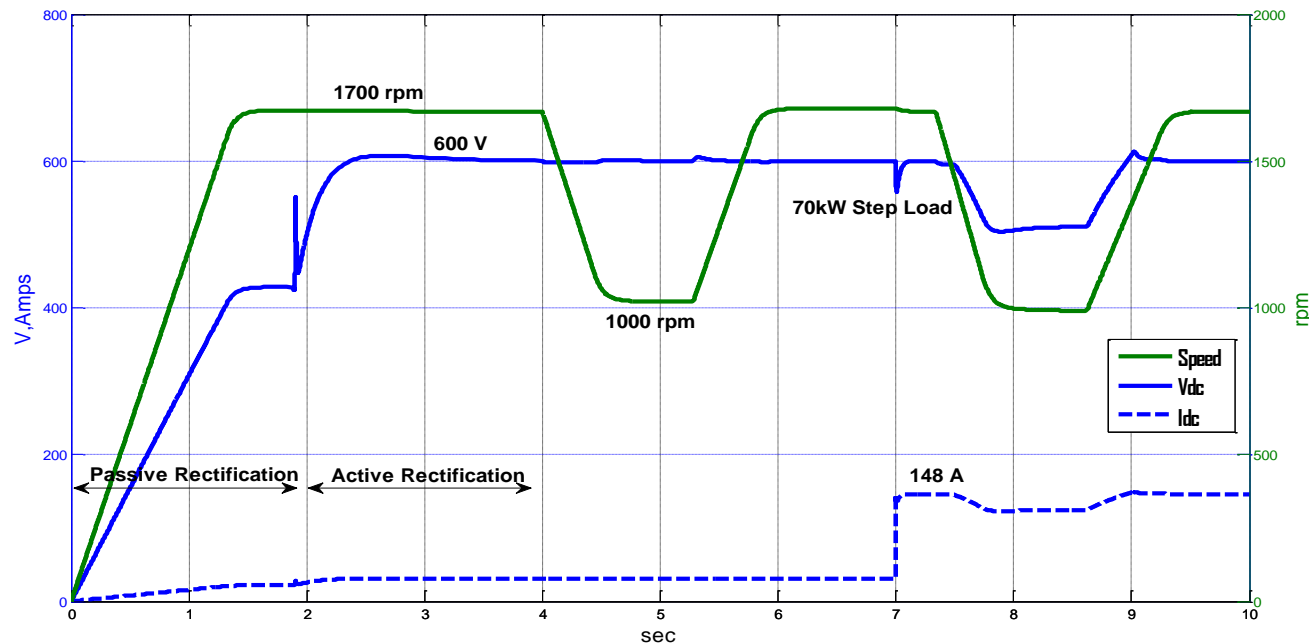


Modeling: Simulating a Vehicle Load Cycle

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Simulation of a Vehicle's Electrical System

- Generator Startup
- Transition between Passive and Active Rectification
- Voltage and Speed Transients
- Generator Controller Current Limits





Conclusions and Future Work

Conclusions

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- Compliance verification with MIL-PRF-GCS600A(ARMY)
 - Established the laboratory capability to validate the results
- M&S tools for power generation system analysis and optimization
 - Characterization of a black-box power generation system, and model development
 - Evaluation of system response with varying DC-link capacitance values and EMI filter parameters, controller gains, and driveline inertia



Future Work



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- Combine component models with those of an engine and high-voltage bus architecture to assess power quality at the vehicle level
- FY13 power generation system SIL and vehicle integration
- Optimization of the bus capacitance for power generation systems
- Vehicle high-voltage bus capacitance allocation